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Probabilistic Analysis of Safe and Unsafe Disagreement in Leader Election Protocols for Virtual Traffic Lights

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What is a Virtual Traffic Light (VTL)?

- A Virtual Traffic Light is a self-organizing traffic control system.
- It allows road vehicles passing an intersection to implement the function of a traffic light without a roadside installation or access to a wireless internet connection.
- Relies entirely on wireless vehicle-to-vehicle (V2V) communication.
- No central control

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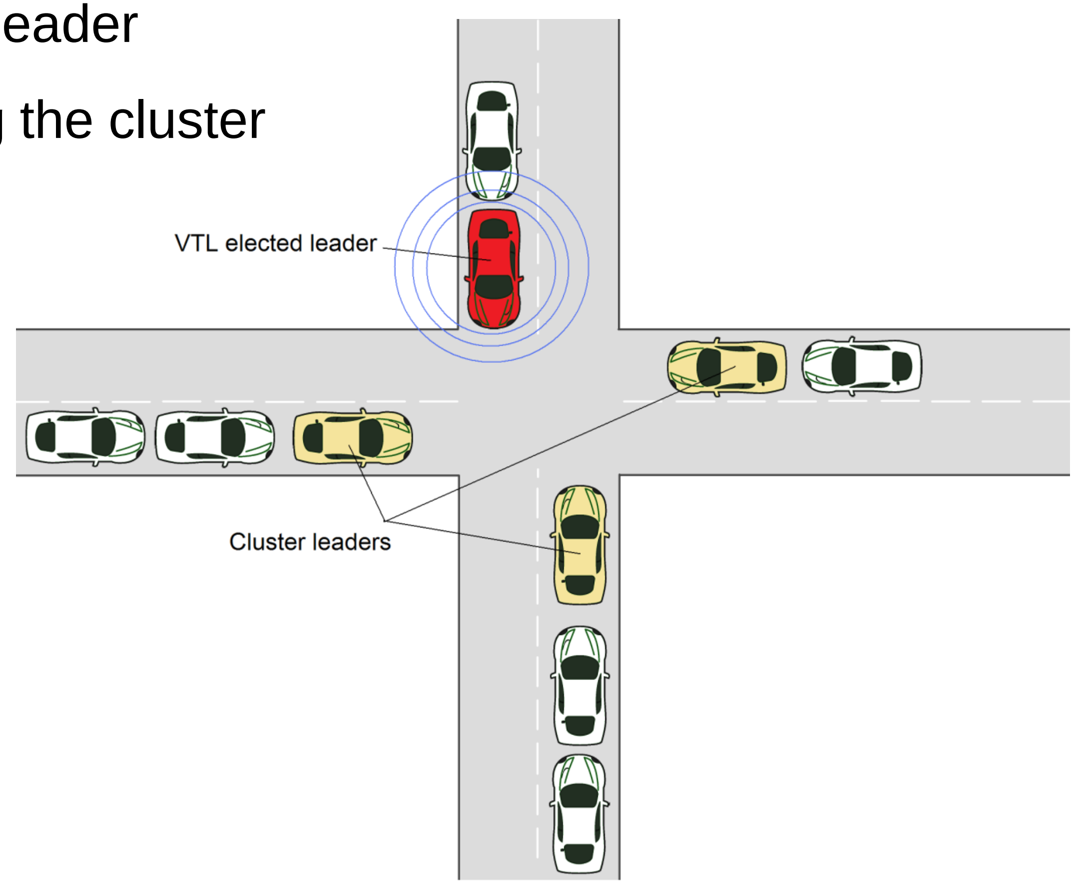
VTL concept by Ferreira et al. (2010)

- Traffic controlled by a VTL leader
- VTL leaders elected among the cluster leaders
- No central control



Key functions:

- Leader election
- Leader handover

Challenges in designing Leader Election Protocols for VTL:s

- It is not feasible to assume ***an upper bound on the number of messages that can be lost*** during the execution of a leader election protocol over a V2V wireless network.

- Consensus cannot be guaranteed in presence of a “high” number of message losses.
  - Impossibility result by Santoro & Widmayer, 1989

- The number of participating nodes and their identities is ***initially unknown*** to all nodes => a node (vehicle) may have an incorrect view of the system size *n.*

Assumptions

- Fault model: receive omissions
  - Message losses on the receiver side
  - Constant failure probability of all message receptions
- System model: synchronous distributed system
  - Round based communication
  - The number of communication rounds is ***fixed at design time***
  - Each node broadcasts one message per round
- A node (vehicle) either ***selects a leader*** or ***aborts***
- A node may have ***an incorrect view*** of the system size n.

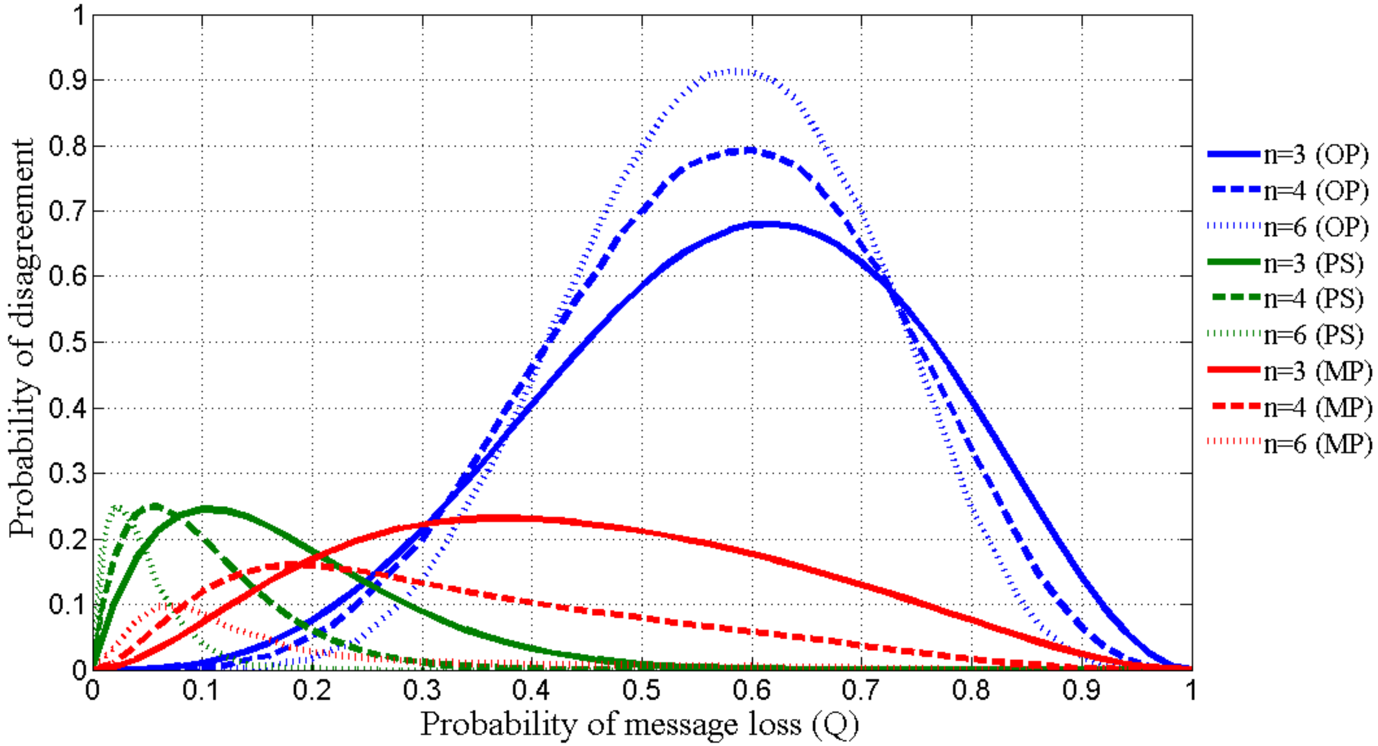
Three protocols

- Whether a node (vehicle) will ***select a leader*** or ***abort*** is determined by a ***decision criterion*** executed as the final step in each instance of the protocol.
- We constructed three protocols with different decision criterions, which we denote as
  - Optimistic
  - Pessimistic
  - Moderately pessimistic
- All three protocols rely on a ***potentially unreliable oracle*** to determine the system size n.

Possible system-wide outcomes

- **Agreement on a leader** - all nodes select *the same* leader.
- **Agreement on abort** - all nodes decide to abort due to insufficient information (too many messages have been lost).
- **Disagreement** – some nodes decide to abort and others decide on a leader.
- We can categorize disagreement in two main classes:
  - **Safe disagreement** - some nodes decides to abort and other nodes decide on *the same leader*.
  - **Unsafe disagreement** - at least two nodes decide on different leaders.

No. of nodes (*n*) = 3, 4, 6, R=2, receive omissions, perfect oracles => no unsafe disagreement

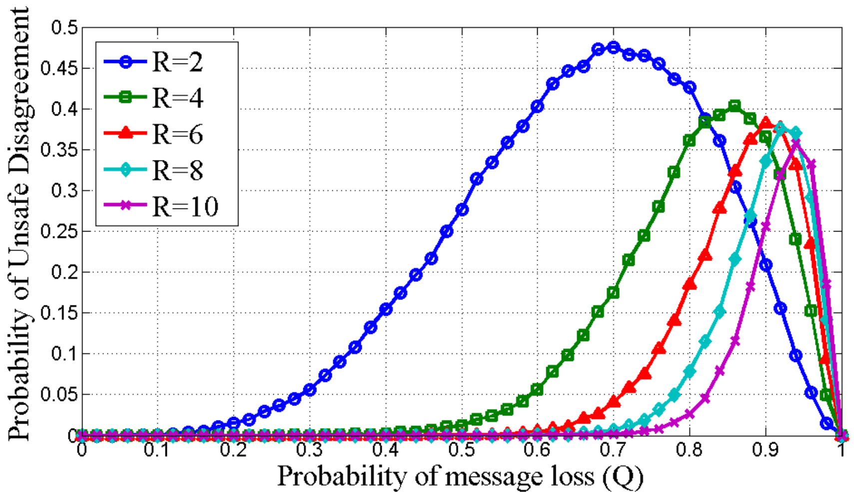


n = no. of nodes (cluster leaders)
R = no. of communication rounds
Q = probability of message lost at receiver (receive omissions)
Perfect oracles = all nodes have the correct view of the system size *n*.

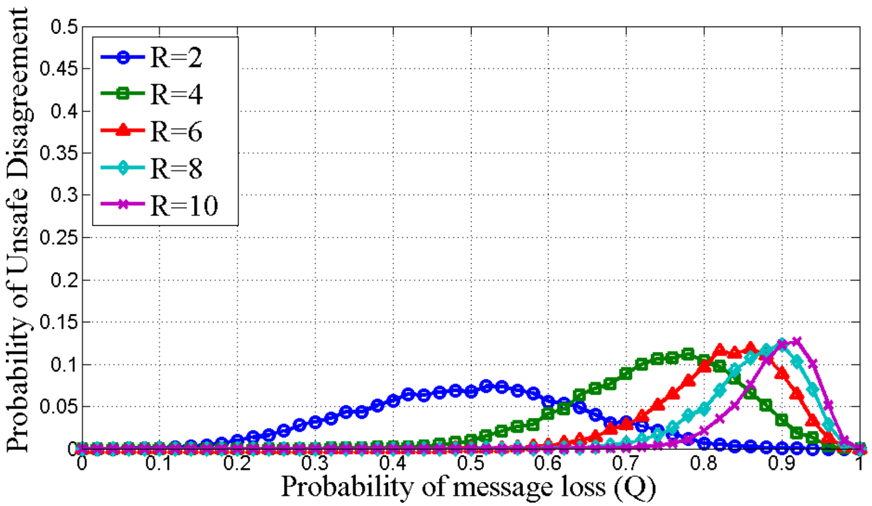
OP = optimistic decision criterion
PS = pessimistic decision criterion
MP = moderately pessimistic decision criterion

Number of nodes = 4, receive omissions, non-perfect oracles => unsafe disagreement possible

n = 4 (true value) , all oracles incorrectly assume a system size of 2.



Optimistic decision criterion



Pessimistic decision criterion

n = no. of nodes (cluster leaders)
R = no. of communication rounds
Q = probability of message lost at receiver (receive omissions)
Non-perfect oracles = not all nodes have the correct view of the system size *n*.

Conclusions

- We introduced the concepts of ***safe and unsafe disagreement*** in V2V wireless networks.
- Unsafe disagreement does not occur ***if all nodes have a correct view*** of the system size *n* (= perfect oracles).
- Unsafe disagreement does not occur ***if one or more oracles overestimate and no oracle underestimate*** the size of the system.
- Unsafe disagreement occurs only if ***one or more oracles underestimate*** the size of the system.